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Standard Models and Split Supersymmetry from Intersecting Brane Orbifolds

Christos Kokorelis

Institute of Nuclear Physics, N.C.S.R. Demokritos, GR-15310, Athens, Greece
and
Nuclear and Particle Physics Sector, Univ. of Athens, GR-15771 Athens, Greece

We construct four dimensional three generation non-supersymmetric $SU(3)_c \times SU(2)_L \times U(1)_Y$ intersecting D6-brane models that break to just the SM at low energies; the latter using a minimal number of three and five stacks. At three stacks we find exactly the SM chiral spectrum and gauge group; the models using tachyonic Higgs excitations flow to only the SM. At five stacks we find non-supersymmetric models with the massless fermion spectrum of the N=1 Standard Model and massive exotic non-chiral matter; these models flow also to only the SM. At eight stacks we find non-supersymmetric SM-like models with massless exotics, the latter forming pairs with opposite hypercharges. The present models are based on orientifolds of $\mathbf{T^6}/(\mathbf{Z_3} \times \mathbf{Z_3})$ compactifications of IIA theory and have all complex structure moduli naturally fixed by the orbifold symmetry. The full spectrum of the three generation models accommodates also ν_R^c's. Baryon number is not gauged but as the string scale is geometrically close to the Planck scale proton stability is guaranteed. Moreover, we point out the relevance of intersecting/and present D6-brane constructions on ideas related to existence of split supersymmetry in nature. In this context we present models, with tachyonic set of Higgses, that achieve the correct supersymmetric GUT value for the Weinberg angle $sin^2\theta = \frac{3}{8}$ at the string scale $M_{GUT} = 2 \cdot 10^{16}$ GeV and have only the SM at low energy, also discussing in this context the existence of models with light gauginos and higgsinos. These models satisfy most of the requirements necessary for the existence of split susy scenario.

1 INTRODUCTION

Model building attempts in the context of string theory have by far been explored both into the context of heterotic string compactifications (HSC) and in N=1 orientifolds (OR) where a number of semirealistic models have been explored and analyzed [1]. In the absence of a dynamical principle for selecting a particular string vacuum and simultaneously fix all moduli, the standard lore is to systematically analyze on phenomenological grounds the different string compactifications.

Over the last few years, model building attempts coming from intersecting branes (IB's) [2]-[37] have received a lot of attention as it become possible to construct [1] - for the first time in string theory - non-supersymmetric (non-SUSY) four dimensional (4D) vacua with only the SM at low energy using intersecting D6-branes [8, 9, 10] from 4D toroidal orientifolds of type IIA. We note that constructions with D6-branes intersecting at angles are T-dual to constructions with magnetic deformations (MD) [3, 4], even though intersecting D-brane models has not yet been shown to be reproducible by the MD side. These IB models have interesting properties like, a stable proton, mass terms for all SM matter and also incorporate right handed neutrinos. In this context, vacua based on non-SUSY Pati-Salam GUT constructions (with a stable proton), which break to the SM at low energy, giving masses to all exotics, have been also constructed and analyzed [11]. All the above models have vanishing RR tadpoles and uncancelled NS-NS tadpoles (coming from the closed string sector), the latter acting as an effective cosmological constant [6]. On phenomenological grounds the string scale may be at the TeV; however as the D6-branes wrap the whole of internal space and there are no dimensions transverse to all branes, the presence of a TeV scale cannot be explained according to the AADD mechanism [33].
Nevertheless, we note that intersecting brane worlds accommodate nicely the AADD [33] solution to the gauge hierarchy problem by providing us with the only known string realization of this mechanism, that is toroidal models with large extra dimensions that break only to the SM at low energy (these models have broken supersymmetry). The latter models are based on D5-branes intersecting at angles in the compact part of $T^4 \times C/Z_N$ [12, 13].

Non-supersymmetric semirealistic GUTS in Z_3 orientifolds [6] of intersecting branes have been also analyzed and SU(5) and flipped SU(5) GUTS has also been shown to exist

[1]In IB's chiral fermions get localized in the open string sector of the theory

[18] that break only to the SM at low energies [2].

Moreover, the construction of vacua which have only the MSSM at low energies, has been also studied using either N=1 supersymmetric models or N=0 models that localize in part of their spectrum the MSSM. In the latter case, the MSSM is localized as part of the non-supersymmetric open string spectrum [15, 17]. In the former case, N=1 semirealistic supersymmetric vacua based on intersecting D6-branes has also been explored in four dimensional orientifolds of type IIA on $\mathbf{T^6/Z_2 \times Z_2}$ [7], $\mathbf{T^6/Z_4}$[22], $\mathbf{T^6/Z_2 \times Z_4}$ [23], and $\mathbf{T^6/Z_6}$ [24], where also GUT constructions have been analyzed [7, 25, 28]. The main characteristics of these models is that not all complex structure moduli are fixed and in some of these constructions part of their spectrum includes those of the N=1 SM in addition to extra massless chiral exotics [7], [24] or massless non-chiral exotics [22] [We also note that there are model building attempts from orientifolds of Gepner models where also the N=1 SM, with three pairs of H_u, H_d MSSM Higgs multiplets, was found but in the presence of extra massless non-chiral exotics [38].]. In [24] the spectrum of the N=1 SM with no Higgs multiplets appears. The required 3 pairs of Higgs doublets H_u, H_d appear in [24] only after brane recombination (BR) is used. BR corresponds to processes that are not described by a free world-sheet CFT and thus CFT methods cannot be applied (rather string field theory may be used) in the calculation of spectrum and interactions. In those cases, brane recombination (BR) proceeds via flat directions that involve the presence of Higgs multiplets in previously massive N=2 sectors. BR can also may be used to perform similar transition examples in the five stack N=0 SM constructions of the present work. However, at the present state of the art BR models can not be considered as realistic. N=1 supersymmetric models may not be yet constructed from the present $Z_3 \times Z_3$ orientifold IB models. Instead in the present work we will focus our attention to the construction of non-supersymmetric models.

The purpose of this paper is to discuss the appearance of N=0 supersymmetric models that break to only the SM either without any exotics being present or with a minimal number of non-chiral massive exotics. These models are based on four dimensional type IIA orientifolds on $\mathbf{T^6/Z_3 \times Z_3}$ with D6-branes intersecting at angles.

In the N=0 intersecting D6-brane models presented in this work there are several interesting features :

a) Models which achieve the successful GUT result for the Weinberg angle, $sin^2\theta = 3/8$

[2] For some attempts to derive the SM but not based in a string construction see [39].

are presented.
b) fewer moduli are left unfixed in the effective theory as all models have all complex structure moduli fixed, something which is known to happen only in the intersecting brane Z_3 orientifolds of [6] and to models with fluxes [45].
c)at the level of 3-stacks, we find models which break to only the SM at low energy. We also find non-susy models - at 3- and 5-stacks - with the chiral spectrum of the N=1 SM (with ν_R's) in the presence of three pairs of MSSM Higgsinos H_u, H_d in addition to massive non-chiral exotics which again break to the SM at low energies. A comment is in order. In this work when we will speak about the SM, we will keep in mind that in all models there is no mass term for the up-quarks [The same effect persists in the models of [6, 46]].
Recently the split supersymmetry scenario (SS) was proposed [41]. In this respect we propose intersecting D-brane models - in section 8 - that provide evidence for a natural realization of the SS scenario in intersecting D-brane models as they satisfy most of the relevant criteria required by the SS existence.

In section 2 we will present the key features of the $\mathbf{T^6/Z_3 \times Z_3}$ constructions, including the gauge group structure and spectrum rules. The details of the construction together with examples for GUT model building will be presented in a companion paper [19]. In section 3 we discuss N=0 three generation (3G) non-supersymmetric SMs with the fermion spectrum of the N=1 SM and extra non-chiral massive exotics. Higgsinos get massive and the models break to the SM at low energy. In section 4 we also discuss the deformation of these N=0 3G models to other N=0 3G models which have only the SM the low energy without any exotics being present. In section 5, we examine whether or not it is possible to construct N=0 models by using 4-stacks of D6's. We find that the only N=0 models that are possible to be constructed suffer from multiwrappings. In section 6 we present more possibilities for constructing N=0 3G models by using five stacks of intersecting D6-branes. Here it is also possible to construct N=0 vacua with only the SM at low energy and extra non-chiral massive exotics. In section 7 we construct N=0 models with N=1 susy preserving D6-branes by using eight (8) stacks of D6-branes. All N=0 models have the N=1 SM fermionic spectrum and two massless pair of exotics with opposite hypercharges surviving to low energies. In section 8 we present arguments supporting the relevance of intersecting D-brane constructions to some new ideas related to the existence of split supersymmetry in nature and also discuss models with $sin^2\theta = 3/8$ at the string

scale that satisfy most of the conditions required for the split susy scenario. Section 9 contains our conclusions.

2 SPECTRUM ON $T^6/Z_3 \times Z_3$ ORIENTIFOLDS, RR TADPOLES & ANOMALY CANCELLATION

Our orientifold constructions originate from IIA theory compactified on the $\mathbf{T^6}/(\mathbf{Z_3} \times \mathbf{Z_3})$ orbifold, where the latter symmetry is generated by the twist generators (where $\alpha = e^{\frac{2\pi i}{3}}$) $\theta : (z_1, z_2, z_3) \to (\alpha z_1, \alpha^{-1} z_2, z_3)$, $\omega : (z_1, z_2, z_3) \to (z_1, \alpha z_2, \alpha^{-1} z_3)$, where θ, ω get associated to the twists $v = \frac{1}{3}(1, -1, 0)$, $u = \frac{1}{3}(0, 1, -1)$. Here, $z^i = x^{i+3} + i x^{i+5}$, $i = 1, 2, 3$ are the complex coordinates on the T^6, which we consider as being factorizable for simplicity, e.g. $T^6 = T^2 \otimes T^2 \otimes T^2$. In addition, to the orbifold action the IIA theory is modded out by the orientifold action ΩR that combines the worldsheet parity Ω and the antiholomorphic operation $R : z^i \to \bar{z}^i$. Because the orbifold action has to act crystallographically on the lattice the complex structure on all three T^2 tori is fixed to be $U_A^I = 1/2 - i\sqrt{3}/2$. The lattice vectors are defined as $e_1 = (1, 0)$, $e_2 = (-1/2, \sqrt{3}/2)$ and the ΩR action is along the horizontal directions across the six-torus. The model contains nine kinds of orientifold planes, that get associated to the orbit $\mathcal{O}$ consisting of the actions of ΩR, $\Omega R\theta$, $\Omega R\omega$, $\Omega R\theta^2$, $\Omega R\omega^2$, $\Omega R\theta\omega$, $\Omega R\theta^2\omega$, $\Omega R\theta\omega^2$, $\Omega R\theta^2\omega^2$. We will be interested on the open string spectrum and not discuss the closed string spectrum that contains gravitational multiplets and orbifold moduli. In order to cancel the RR crosscap tadpoles introduced by the introduction of the orientifold planes we introduce N $D6_a$-branes wrapped along three-cycles that are taken to be products of one-cycles along the three two-tori of the factorizable T^6. A D6-brane a - associated with the equivalence class of wrappings (n^I, m^I), $I = 1, 2, 3$, - is mapped under the orbifold and orientifold action to its images

$$a \leftrightarrow \begin{pmatrix} n_a^1, m_a^1 \\ n_a^2,\ m_a^2 \\ n_a^3,\ m_a^3 \end{pmatrix}, \ \theta a \to \begin{pmatrix} -m_a^1,\ (n-m)_a^1 \\ (m-n)_a^2,\ -n_a^2 \\ n_a^3,\ m_a^3 \end{pmatrix}, \quad \Omega R a \to \begin{pmatrix} (n-m)_a^1,\ -m_a^1 \\ (n-m)_a^2,\ -m_a^2 \\ (n-m)_a^3,\ -m_a^3 \end{pmatrix}. \quad (2.1)$$

In ΩR orientifolds the twisted disk tadpoles vanish [31]. The $Z_3 \times Z_3$ orientifold models are subject to the cancellation of untwisted RR tadpole conditions [19] given by

$$\sum_a N_a Z_a = 4, \quad (2.2)$$

where

$$Z_a = 2m_a^1m_a^2m_a^3 + 2n_a^1n_a^2n_a^3 - n_a^1n_a^2m_a^3 - n_a^1m_a^2n_a^3 - m_a^1n_a^2n_a^3 - m_a^1m_a^2n_a^3 - m_a^1n_a^2m_a^3 - n_a^1m_a^2m_a^3 \tag{2.3}$$

The gauge group U(N_a) supported by N_a coincident D6$_a$-branes comes from the $a(\tilde{a})$ sector, the sector made from open strings stretched between the a-brane and its images under the orbifold action. In addition, we get three adjoint N=1 chiral multiplets. In the $a(\mathcal{O}b)$ sector - strings stretched between the brane a and the orbit images of brane b - will localize I_{ab} fermions in the bifundamental $(N_a, \bar{N}_b)$ where

$$I_{ab} = 3(Z_aY_b - Z_bY_a), \tag{2.4}$$

and (Z, Y) are the effective wrapping numbers with Y_a given by

$$Y_a = m_a^1m_a^2m_a^3 + n_a^1n_a^2n_a^3 - n_a^1n_a^2m_a^3 - n_a^1m_a^2n_a^3 - m_a^1n_a^2n_a^3 \tag{2.5}$$

The sign of I_{ab} denotes the chirality of the associated fermion, where we choose positive intersection numbers for left handed fermions. In the sector ab' - strings stretching between the brane a and the orbit images of brane b, there are $I_{ab'}$ chiral fermions in the bifundamental (N_a, N_b), with

$$I_{ab'} = 3(Z_aZ_b - Z_aY_b - Z_bY_a), \tag{2.6}$$

The theories also accommodate the following numbers of chiral fermions in symmetric (S) and antisymmetric (A) representations of $U(N_a)$ from open strings stretching between the brane a and its orbit images $(\mathcal{O}a)$,

$$(A_a) = 3(Z_a - 2Y_a), \tag{2.7}$$

$$(A_a + S_a) = \frac{3}{2}(Z_a - 2Y_a)(Z_a - 1) \tag{2.8}$$

Finally, from open strings stretched between the brane a and its orbifold images we get non-chiral massless fermions in the adjoint representation,

$$(Adj)_L : \prod_{i=1}^{3}(L_{[a]}^I)^2 \ , \tag{2.9}$$

where

$$L_{[a]}^I = \sqrt{(m_a^I)^2 + (n_a^I)^2 - (m_a^I)(n_a^I)} \tag{2.10}$$

Adjoint massless matter, including fermions and gauginos that are massless at tree level are expected to receive string scale masses from loops once supersymmetry is broken [3], leaving only the gauge bosons massless, and we will not discuss it further. In the low energy theory, cubic gauge anomalies automatically cancel, due to the RR tadpole conditions (2.2). Mixed U(1)-gauge anomalies also cancel due to the existence of a generalized Green-Schwarz (GS) mechanism (see [19] for further details) that makes massive only one U(1) gauge field given by

$$\sum_a N_a(Z_a - 2Y_a)F_a \tag{2.11}$$

The minimal choice of obtaining an extension of the Standard model (SM) is obtained using three stacks of D6-branes. The spectrum of open strings stretching between intersecting D6-branes is calculated by the use of rules (2.4 - 2.8). To establish notation we will denote the type of sypersymmetries preserved in the closed string sector by the choices of vectors [4] $r_0 = \pm(1/2)(+-+-)$, $r_1 = \pm(1/2)(++--)$, $r_2 = \pm(1/2)(-++-)$, $r_3 = \pm(1/2)(----)$. Supersymmetry may be preserved by a system of branes if each stack of D6-branes is related to the $O6$-planes by a rotation in $SU(3)$, that is the angles $\tilde{\theta}_i$ of the D6-branes with respect to the horizontal direction in the i-th two-torus obeys the condition $\tilde{\theta}_1 + \tilde{\theta}_2 + \tilde{\theta}_3 = 0$. The supersymmetry of the models that is preserved by any pair of branes, that is r_3, is determined by the choice of the orbifold and orientifold action. To examine whether N=0 or N=1 susy models are allowed we have to examine the brane wrappings (n, m). Our current search finds no N=1 supersymmetric models.

3 *THE N=0 "MINIMAL" SUPERSYMMETRIC STANDARD MODEL*

Next, we obtain non-supersymmetric models which localize the fermion spectrum of the intersecting brane N=1 MSSM in addition to a couple of massive - non-chiral - exotics, which subsequently break to only the SM at low energy with the use of the GS mechanism described in the previous section.

[3]See the discussion in the appendix of [8] and comments on section 8.

[4]we follow the notation of the first reference of [11].

3.1 N=0 SM's at low energy with the N=1 MSSM chiral spectrum at M_s

The minimal choice of obtaining the SM gauge group and chiral spectrum is to start from a three stack $U(3)_a \times U(2)_b \times U(1)_c$ D6-brane construction at the string scale.

The choice of wrapping numbers

$$(Z_a, Y_a) = \begin{pmatrix} 1, & 0 \end{pmatrix}, \ (Z_b, Y_b) = \begin{pmatrix} 1, & 1 \end{pmatrix}, \ (Z_c, Y_c) = \begin{pmatrix} -1, & 1 \end{pmatrix} \tag{3.1}$$

satisfies the RR tadpoles and corresponds to the spectrum seen in table (1). We recognize

Matter	$(SU(3) \times SU(2))_{(Q_a,Q_b,Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$3(3,2)_{(1,\ -1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(3,1)_{(2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3,1)_{(-1,\ 0,\ -1)}$	$1/3$
$\{L\ +\ H_d\}$	$6(1,2)_{(0,\ 1,\ -1)}$	$-1/2$
$\{H_u\}$	$3(1,\bar{2})_{(0,\ -1,\ -1)}$	$1/2$
$\{e_L^+\}$	$3(1,1)_{(0,\ -2,\ 0)}$	1
$\{N_R\}$	$9(1,1)_{(0,\ 0,\ 2)}$	0
$\{C_1\}$	$3(3,1)_{(1,\ 0,\ -1)}$	$1/3$
$\{C_2\}$	$3(\bar{3},1)_{(-1,\ 0,\ -1)}$	$-1/3$

Table 1: A three generation non-supersymmetric model with the fermion content of N=1 MSSM on top of the table, in addition to N_R's and three pairs of H_u, H_d Higgsinos. This model predicts nine N_R's. Note that this model mimics models coming from gauge mediation scenarios.

in table (1), the chiral spectrum of the N=1 MSSM with three generations of right handed neutrinos (N_R) and three pairs of massless 'Higgsinos' [5]. Also one U(1) gauge field becomes massive through its BF couplings, namely $3F_a - 2F_b - 3F_c$, while there are two U(1)'s that survive massless the GS mechanism (2.11),

$$U(1)^Y = -(1/3)F_a - (1/2)F_b, \quad U(1)^{add} = F_a - (2/3)F_b - (10/12)F_c \ . \tag{3.2}$$

[5] Instead of one Higgino H_u, H_d pair in the standard global SUSY version of the MSSM

The $U(1)^{add}$ could be broken by a tachyonic singlet excitation charged under F_c, namely $\tilde{N}_R$, that plays the role of the 'superpartner' of N_R, thus leaving only the hypercharge massless at low energies, below the scale set by $\langle \tilde{N}_R \rangle$. The following Yukawa couplings for the quarks, leptons and exotics X_i are allowed:

$$Y = \lambda_d Q_L d_L^c \tilde{H}_d \tilde{N}_R / M_s \; + \; \lambda_u^{ij} L^j N_R^i \tilde{H}_u \; + \; \lambda_e L E_R \tilde{H}_d \tilde{N}_R / M_s \; + \\ \lambda_c C_1 C_2 \tilde{N}_R \; + \lambda_\mu H_u H_d \tilde{N}_R \tag{3.3}$$

where $i = 1, .., 9$, $j = 1, 2$. The exotic triplets C_i form a Dirac mass term which receives a mass of order M_s from the vev of $\tilde{N}_R$. The form of this coupling provide us with the bilinear mixing, that in a N=1 susy theory, would have played the role of a superpotential μ-term. Moreover, the two Higgsinos H_u, H_d receive a Dirac mass term from the last term in (3.3) of order of the string scale, as the natural scale of $\langle N_R \rangle = M_s$.

We remind that because the D6-branes wrap along all the T^6, the string scale is high and close to the Planck scale. Thus a value for the Higgsinos which can be at M_s or lower is set by the values of the Yukawa coupling coefficients λ_μ. Large exponential suppression of a n-point interaction of Yukawa interactions in the form

$$\lambda_\mu \sim e^{-A} \tag{3.4}$$

is a natural aspect of IBW's due to their dependence on the worldsheet area A, in string units, located between their brane intersections [30, 11]. Hence a light higssino condensate of order of electroweak symmetry breaking $\upsilon = 246$ GeV can be obtained, assuming $M_s = 10^{16}$ GeV, with $A = 31$.

The quarks - apart for the u-quark which remain massless as the relevant coupling is excluded from charge conservation - and leptons receive non-zero masses from the Yukawa couplings in the 1st line of (3.3). Thus at low energy we have the SM - with the up quark remaining massless after electroweak symmetry breaking - and nine (9) generations of right handed neutrinos. A comment is in order. As the D6-branes involved wrap on generic angles the spectrum of table (1) is non-supersymmetric. Unfortunately, we were only able to find wrappings that render the models non-supersymmetric [6].

One can also check that the choice of effective wrappings

$$(Z_a, Y_a) = \begin{pmatrix} 1, & 0 \end{pmatrix}, \; (Z_b, Y_b) = \begin{pmatrix} 1, & 1 \end{pmatrix}, \; (Z_c, Y_c) = \begin{pmatrix} -1, & -2 \end{pmatrix} \tag{3.5}$$

[6] These choices have at least one zero entry among the (n, m) wrappings.

$Brane$	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$
$\{a\}$	$(1,\ 0) \times (0,\ 1) \times (0,\ -1)$
$\{b\}$	$(0,\ 1) \times (1,\ 0) \times (0, 1)$
$\{c\}$	$(0,\ -1) \times (1,\ 1) \times (0, -1)$

Table 2: Wrapping numbers responsible for the generation of the N=0 models of table (1), that have the chiral spectrum of the intersecting brane N=1 MSSM.

gives us also the N=0 chiral SM spectrum [7] of table (1) with the same hypercharge assignments.

4 EXACTLY THE SM FROM THREE STACKS

In this section, we will construct non-supersymmetric models which have exactly the SM gauge group and chiral spectrum and no exotics present. These models will be constructed as a deformation of the models that appeared in table (1). Also in these models there is no mass term allowed from the up-quarks.

4.1 SM Deformations of N=0 SM'S from three stacks

• Let us make the choice of wrapping numbers

$$(Z_a, Y_a) = \left(1, \ \ 0 \right), \ (Z_b, Y_b) = \left(1, \ \ 1 \right), \ (Z_c, Y_c) = \left(-1, \ \ -1 \right) \tag{4.1}$$

This choice satisfies the RR tadpoles and corresponds to the spectrum seen in table (3). The intersection numbers are

$$\begin{gathered} I_{ab} = 3, \quad (A)_a = 3, \quad I_{bc^\star} = 3 \ , \\ (A)_b = -3, \quad I_{ac} = -3, \quad (A+S)_c = -3 \end{gathered} \tag{4.2}$$

From (2.11) there is one anomalous U(1) which becomes massive

$$U(1)^{massive} = 3F_a - 2F_b + F_c \tag{4.3}$$

[7] Apart for some differences in the U(1) charges involved

Matter	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$3(3,2)_{(1,\ -1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(\bar{3},1)_{(2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3,1)_{(-1,\ 0,\ 1)}$	$1/3$
$\{L\}$	$3(1,2)_{(0,\ 1,\ 1)}$	$-1/2$
$\{e_L^+\}$	$3(1,1)_{(0,\ -2,\ 0)}$	1
$\{N_R\}$	$3(1,1)_{(0,\ 0,\ -2)}$	0

Table 3: A three generation chiral (open string) spectrum accommodating the SM. The required Higgs may come from bifundamental N=2 hypermultiplets in the N=2 bc, $bc^\star$ sectors [8, 9, 10] that may trigger brane recombination.

and two anomaly free U(1)'s that correspond to the hypercharge and an extra U(1)

$$U(1)^Y = -\frac{1}{3}F_a - \frac{1}{2}F_b, \quad U(1)^{ex} = -3F_a + 2F_b + 13F_c \tag{4.4}$$

We regognize in table (3) exactly the chiral spectrum of the SM as at this point the spectrum for generic angles is non-supersymmetric. Exactly the same - but with opposite U(1) charges - non-supersymmetric chiral spectrum construction was found in [6] from intersecting D6-branes in Z_3 orientifolds. In [6] and in the present models the breaking of the extra U(1) surviving massless the Green-Schwarz mechanism proceeds via tachyonic excitations in the sector accommodating the right handed neutrino.

Choices of wrappings satisfying the constraints (4.1) can be seen in table (4). Other choices of wrappings solving the RR tadpole conditions may be seen in table (5). Baryon (and lepton) number is not conserved but as the string scale in these models is naturally close to Planck scale we do expect a natural enhancement of gauge mediated proton decay modes and thus proton stability is guaranteed.

The exchange of wrappings

$$(Z_a, Y_a) \leftrightarrow (Z_b, Y_b) \tag{4.5}$$

is a symmetry of the theory as the spectrum and hypercharge of table (3) do not change under the exchange (4.5), which just reverses the $U(1)_a$, $U(1)_b$ charges [8].
There is another symmetry under which the spectrum remains invariant. The spectrum remains invariant under the interchanges

$$(n, m)_a \leftrightarrow (n, m)_b, \quad (n, m)_a \leftrightarrow (n, m)_c, \quad (n, m)_b \leftrightarrow (n, m)_c \tag{4.6}$$

applied in the wrappings of tables (4), (5), thus resulting in new N=0 models. Some examples of this spectrum symmetry applied in the wrappings of table (5) may be seen in appendix A. The Higgs available for electroweak symmetry breaking (ESB) may come

Brane	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$	SUSY preserved
$\{a\}$	$(1,\ 0) \times (0,\ 1) \times (0,\ -1)$	$-$
$\{b\}$	$(1,\ 1) \times (1,\ 0) \times (-1, -1)$	$-$
$\{c\}$	$(1,\ \ 1) \times (-1,\ 0) \times (-1,\ \ -1)$	$-$

Table 4: Wrapping numbers responsible for the generation of the three stack D6-brane non-supersymmetric Standard Models of table (3).

from bifundamental scalars that are part of the massive spectrum of the N=2 sector of open strings stretched between the U(2) brane and the brane image of the U(1) c-brane ; as the b,c branes are parallel in at least one complex plane along the different orbits. The Higgs scalars become tachyonic [see also [8, 9, 10]] by varying the distance between the parallel branes. The available electroweak Higgs have the quantum numbers

$$h_1 = (1, 2)_{(0,\ 1,\ -1)},\ h_2 = (1, \bar{2})_{0,\ -1,\ 1)}\ , \tag{4.7}$$

where the allowed Yukawa couplings are given by

$$Y = \lambda_d Q_L d_L^c h_1\ +\ \lambda_\nu L N_R h_2\ +\ \lambda_e L E_R h_1 \tag{4.8}$$

with no mass term for u-quarks.

[8] obviously leaving invariant the hypercharge under field redefinition

$Brane$	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$	SUSY preserved
$\{a\}$	$(1,\ 0) \times (0,\ 1) \times (0,\ -1)$	$-$
$\{b\}$	$(1,\ 1) \times (1,\ 0) \times (-1, -1)$	$-$
$\{c\}$	$(1,\ \ 1) \times (1,\ 1) \times (1,\ \ 0)$	$-$

Table 5: Wrapping numbers responsible for the generation of the three stack non-supersymmetric D6-brane Standard Models of table (3).

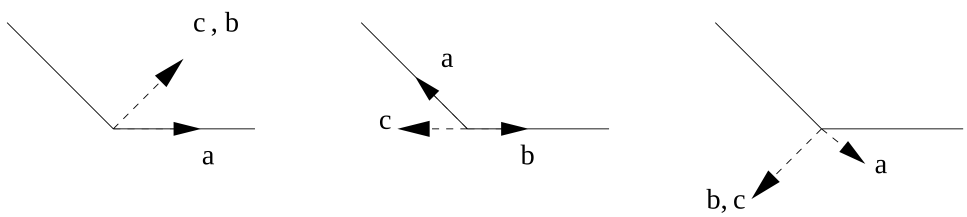

Figure 1: Brane positions in the SM's of table (3) for the wrapping choices of table (4).

•• Another three stack N=0 model with the chiral spectrum of only the SM can be derived from the wrapping numbers (4.1) by deforming around the Y_c wrapping number. Thus the choice of wrappings

$$(Z_a, Y_a) = \begin{pmatrix} 1, & 0 \end{pmatrix},\ (Z_b, Y_b) = \begin{pmatrix} 1, & 1 \end{pmatrix},\ (Z_c, Y_c) = \begin{pmatrix} -1, & 0 \end{pmatrix} \tag{4.9}$$

provide us with the spectrum of table (3) but with reversed $U(1)_c$ charge. In this case the U(1) gauge field which becomes massive through its nonzero coupling to the RR fields is given by $3F_a - 2F_b - F_c$. Also the hypercharge and the extra U(1) are given respectively by

$$U(1)^Y = -\frac{1}{3}F_a - \frac{1}{2}F_b, \quad U(1)^{add} = -\frac{3}{13}F_a + \frac{2}{13}F_b - F_c \tag{4.10}$$

A set of wrappings associated with the effective wrappings (4.9) is given in table (6). A different set of wrappings solving the RR tadpoles may be seen in table (7).

One can also check that the wrapping solutions of table (6) have the S3 permutational symmetry (4.6) that allows the individual pairs of wrappings (n^i, m^i) of the T_i^2 tori to permute with the wrappings of the other T_i^2, $i \neq j$, tori. We also note that in these

Brane	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$	SYSY preserved
$\{a\}$	$(1,\ 0) \times (0,\ 1) \times (0,\ -1)$	–
$\{b\}$	$(1,\ 1) \times (1,\ 0) \times (-1, -1)$	–
$\{c\}$	$(0,\ \ -1) \times (0,\ 1) \times (-1,\ \ 0)$	–

Table 6: Wrapping numbers in the three stack non-supersymmetric D6-brane Standard Models of the wrapping choices (4.9).

models there is no mass term for the up-quarks as well.

Brane	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$	SYSY preserved
$\{a\}$	$(1,\ 0) \times (0,\ 1) \times (0,\ -1)$	–
$\{b\}$	$(1,\ 1) \times (1,\ 0) \times (-1, -1)$	–
$\{c\}$	$(0,\ \ 1) \times (0,\ 1) \times (1,\ \ 0)$	–

Table 7: Wrapping numbers responsible for the non-supersymmetric three stack D6-brane Standard Models of the wrapping choices (4.9).

5 FOUR STACKS OF D6-BRANES and MASSIVE EXOTICS

In this section, we will exhibit the appearance of three generation non-supersymmetric models by using four stacks of D6-branes. We will not give a very detail description of these models as the issue of whether the SM gauge group survives massless to low energies is not well defined due to existence of multiwrappings. We are considering a system of four stacks of D6-branes, namely we start with a gauge group $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$ at the string scale M_s.

5.1 The N=0 Standard Models

We choose the effective wrappings

$$\begin{aligned} (Z_a, Y_a) = \left(1, \ \ 1 \right), \ (Z_b, Y_b) = \left(1, \ \ 0 \right), \\ (Z_c, Y_c) = \left(1, \ \ 1 \right), \ (Z_d, Y_d) = \left(-2, \ \ -2 \right) \ . \end{aligned} \tag{5.1}$$

This set of wrappings satisfies the RR tadpole conditions (2.2) and for the choice of wrappings seen in table (8) the models are non-supersymmetric. The chiral spectrum of the set of wrappings (5.1) that is associated with the hypercharge assignment $U(1)^Y = (1/3)F_a + (1/2)F_b$ may be seen in table (9). At this point a comment is in order. The value of the wrappings of the d-brane across the third tori corresponds to twice multiwrapping across the wrappings $(1, 1)$. The general meaning of such multiwrappings is unclear in the literature, as the presence of the multiwrapping (2,2) = 2(1,1) is claimed by some authors that corresponds to a gauge group enhancement $U(1)_d \to U(1) \times U(1)$ [We will see in the next section that such multiwrappings are absent from the five stack intersecting D6-brane constructions].

Brane	$(n^1, m^1)(n^2, m^2)(n^3, m^3)$	SUSY preserved
$\{a\}$	$(1,\ 1)(1,\ 0)(-1,\ -1)$	$-$
$\{b\}$	$(1,\ 0)(0,\ 1)(0, -1)$	$-$
$\{c\}$	$(1,\ \ 1)(1,\ 0)(-1,\ \ -1)$	$-$
$\{d\}$	$(1,\ 1)(1,\ 0)(2,\ 2)$	$-$

Table 8: Wrapping numbers in the four stack D6-brane Standard-like Models that are generated by the choice of effective wrappings (5.1).

These N=0 SM-like models are indistinguisable under the exchange

$$d_L^c \leftrightarrow X_2, \quad L \leftrightarrow H_d \ . \tag{5.2}$$

For completeness reasons we list the Yukawa couplings

$$\begin{aligned} Y_{(table\ 9)} \ = \ & \lambda_d Q_L d_L^c H_d^H S_2^H / M_s \ + \ \lambda_e L e_L^+ H_d^H S_2^H / M_s + \ \lambda_\nu L \nu_L^c H_u^H S_3^H / M_s \ + \\ & \lambda_\mu^{(4)} H_u H_d S_3^H S_2^H / M_s \ + \ \lambda_{(12)} X_1 X_2 S_3^H S_2^H / M_s \ , \end{aligned} \tag{5.3}$$

Matter for $\mathbf{Y^1}$	Y^1	$(SU(3) \times SU(2))_{(Q_a,\ Q_b,\ Q_c,\ Q_d)}$
$\{Q_L\}$	$1/6$	$3(\bar{3}, 2)_{(-1,\ 1,\ 0,\ 0)}$
$\{u_L^c\}$	$-2/3$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0,\ 0)}$
$\{d_L^c\}$	$1/3$	$3(1, 1)_{(1,\ 0,\ 0,\ 1)}$
$\{L\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 1)}$
$\{H_u\}$	$1/2$	$3(1, 2)_{(0,\ 1,\ -1, 0)}$
$\{H_d\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 1)}$
$\{e_L^+\}$	1	$3(1, 1)_{(0,\ 2,\ 0,\ 0)}$
$\{S_1 \equiv \nu_L^c\}$	0	$3(1, 1)_{(0,\ 0,\ 0,\ -2)}$
$\{S_2\}$	0	$6(1, 1)_{(0,\ 0,\ 0,\ -2)}$
$\{S_3\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 1)}$
$\{X_1\}$	$-1/3$	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0)}$
$\{X_2\}$	$1/3$	$3(3, 1)_{(1,\ 0,\ 0,\ 1)}$

Table 9: The three generation N=0 SM-like models from four stacks of intersecting branes with its chiral spectrum with three pairs of Higgsinos and right handed neutrinos. Either one of the gauge multiplets S_I could be identified as the one associated with the right handed neutrino. The exotics triplets X_I receive a Dirac mass only with the choice of hypercharge associated to Y^1. The scalar massive superpartners of the singlets S_2, S_3 - after they become tachyonic - may be used to break the extra U(1)'s. However, the issue of weather or not the only the SM survives only at only energy is diluted from the existence of multiwrappings in table (8).

where by H_d^H, H_u^H, S_3^H, S_2^H we denote the massive 'superpartners' of the matter H_d, H_u, S_3, S_2 respectively. The $H_u H_d$, $X_1 X_2$ exotic pairs form Dirac mass terms respectively, that receive a non-zero mass from the combined effect of the vevs of the scalar superpartners of S_2, S_3 which become tachyonic.
All SM fermions but the one associated to u_L^c transform in bifundamentals. Moreover the Yukawa couplings give masses to all quarks and leptons but the u-quark, for which the relevant term is excluded from charge conservation.

We however note that under the brane recombination (BR) $\tilde{c} = c + d$, the four stack

models of table (9) flow to the non-supersymmetric three stack models of table (10).

Matter	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$3(\bar{3}, 2)_{(-1,\ 1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3, 1)_{(1,\ 0,\ -1)}$	$1/3$
$\{L\}$	$3(1, 2)_{(0,\ -1,\ 1)}$	$-1/2$
$\{e_L^+\}$	$3(1, 1)_{(0,\ 2,\ 0)}$	1
$\{N_R\}$	$3(1, 1)_{(0,\ 0,\ -2)}$	0
$\{S_0\}$	$6(1, 1)_{(0,\ 0,\ -2)}$	0

Table 10: A three generation non-supersymmetric chiral (open string) spectrum accommodating the SM that result from brane recombination on the SMs of table (9). The extra singlet becomes massive by its coupling to the tachyonic scalar superpartner. The latter may be also be used to break the extra U(1), beyond hypercharge, surviving massless the Green-Schwarz mechanism.

We also note that the wrappings coming from the interchanges (4.6) are still a symmetry of the spectrum.

6 ONLY THE (N=0) SM FROM FIVE STACKS OF D6-BRANES

In this section, we will investigate the possibility to construct N=0 models by using a higher numbers of stacks, namely five stack vacua. In these models the SM will survive massless below the string scale to low energies. After the Green-Schwarz anomaly cancellation the N=0 models will localize the massless fermion spectrum of the N=1 SM, which in turn will be reduced with the help of Higgs tachyons to that of only the SM at low energies. The five stack configuration involves the initial localization of chiral models with a $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d \times U(1)_e$ gauge group at the string scale.

6.1 The N=0 Models

These N=0 models are constructed from the effective wrapping numbers

$$(Z_a, Y_a) = \Big(1\ ,\ \ 1 \Big),\ \ (Z_b, Y_b) = \Big(1\ ,\ \ 0 \Big),\ \ (Z_c, Y_c) = \Big(1,\ \ 1 \Big),$$
$$(Z_d, Y_d) = \Big(-1\ ,\ \ -1 \Big),\ \ (Z_e, Y_e) = \Big(-1,\ \ -1 \Big)\ . \tag{6.1}$$

The above choice of wrapping numbers satisfies the RR tadpole cancellation condition (2.2). The corresponding three generation chiral spectrum can be seen in table (11).

Matter for $\mathbf{Y^1}$	Y^1	$(SU(3) \times SU(2))_{(Q_a,\ Q_b,\ Q_c,\ Q_d,\ Q_e)}$
$\{Q_L\}$	1/6	$3(3, \bar{2})_{(-1,\ 1,\ 0,\ 0,\ 0)}$
$\{u_L^c\}$	$-2/3$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0,\ 0,\ 0)}$
$\{e_L^+\}$	1	$3(1, 1)_{(0,\ 2,\ 0,\ 0,\ 0)}$
$\{d_L^c\}$	1/3	$3(1, 1)_{(1,\ 0,\ 0,\ 1,\ 0)}$
$\{H_u\}$	1/2	$3(1, 2)_{(0,\ 1,\ -1,\ 0,\ 0)}$
$\{L\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 1,\ 0)}$
$\{H_d\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 0,\ 1)}$
$\{S_3 \equiv \nu_L^c\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 1,\ 0)}$
$\{S_1\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ -2,\ 0)}$
$\{S_2\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ 0,\ -2)}$
$\{S_4\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 0,\ 1)}$
$\{S_5\}$	0	$6(1, 1)_{(0,\ 0,\ 0,\ -1,\ -1)}$
$\{X_1\}$	$-1/3$	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0,\ 0)}$
$\{X_2\}$	1/3	$3(3, 1)_{(1,\ 0,\ 0,\ 0,\ 1)}$

Table 11: On the top of the table the N=0 models with the three generation MSSM chiral spectrum with three pairs of Higgsinos and right handed neutrinos. Either one of the gauge multiplets S_I could be identified as the one associated with the right handed neutrino. The exotics triplets X_I form a Dirac mass term, leaving only the SM at low energy.

The analysis of U(1) anomalies in the models shows that there is a massive U(1) given by the combination $U(1)^{(1)} = -3F_a + 2F_b - F_c + F_d + F_e$ and also another four U(1)'s -

including the hypercharge - which survive massless the Green-Schwarz mechanism, namely the following

$$U(1)^{(2)} = \frac{1}{3}F_a + \frac{1}{2}F_a \ , \quad U(1)^{(3)} = 3F_a - 2F_b - 13F_c$$
$$U(1)^{(4)} = 3F_a - 2F_b + F_c + 7F_d + 7F_e \ , \quad U(1)^{(5)} = F_d - F_e \ . \tag{6.2}$$

The extra U(1)'s may be broken by the vevs of vevs of the superpartners of the S_1, S_2, S_4, S_5, namely the S_1^H, S_2^H, S_4^H, S_5^H, Thus for example S_4^H may be used to break $U(1)^{(3)}$, S_5^H may be used to break $U(1)^{(5)}$, while S_1^H, S_2^H could be used to break $U(1)^{(4)}$. Thus at low energies only the SM gauge group survives.

We construct N=0 models with the spectrum of table (11). A choice of wrappings can be seen in table (12). Further examples of wrappings which describe equivalent models can be seen in appendix C, in tables (24), (25) and (26). These models of appendix C are constructed by the application of the interchange of wrappings - the latter being a symmetry of the spectrum - in (4.6) to the wrappings of table (12). The models of table (12) are non-susy [9].

Brane	$(n^1, m^1)(n^2, m^2)(n^3, m^3)$	SUSY Preserved
$\{a\}$	$(1,\ 1)(1,\ 0)(-1,\ -1)$	$-$
$\{b\}$	$(1,\ 0)(0,\ 1)(0, -1)$	$-$
$\{c\}$	$(1,\ 1)(1,\ 0)(-1,\ -1)$	$-$
$\{d\}$	$(1,\ 1)(1,\ 0)(1,\ 1)$	$-$
$\{e\}$	$(1,\ 1)(1,\ 1)(1,\ 0)$	$-$

Table 12: Wrapping numbers responsible for N=0 supersymmetry in the five stack 4D three generation intersecting D6-brane models.

We note that in all models there is no mass term for the up-quarks which is excluded from charge conservation.

• **Model A**

Yukawa couplings for the quarks and leptons and exotic triplets X_i of the models appearing in table (11) are given by

$$Y^{(table\ 11)} \ = \ \lambda_d Q_L d_L^c H_d^H S_4^H / M_s \ + \ \lambda_e L e_L^+ H_d^H S_5^H / M_s \ + \ \lambda_\nu L \nu_L^c H_u^H S_1^H / M_s \ +$$

[9] We follow the notation of the first reference of [11].

$$\lambda_x X_1 X_2 S_4^H \ + \ H_u H_d (\lambda_\mu^{(2)} S_3^H S_5^H + \lambda_\mu^{(1)} S_4^H S_2^H)/M_s \tag{6.3}$$

The mass term for the exotic triplets couples to the vev of the superpartner of S_4. As the presence of these triplets can mediate scalar mediated proton decay modes such as the

$$((\bar{u}_L^c)_\alpha (d_L)_\beta)((\bar{d}_L^c)_\gamma \nu_L)\epsilon_{\alpha\beta\gamma} \ , \tag{6.4}$$

it is necessary that they receive a mass which it is at least 10^{16} GeV or higher, such as proton decay is enhanced beyond the observable present limit $\Gamma^{-1}_{expected} \ (p \rightarrow e_L^+ \pi_o) \geq 10^{33}$ yrs [See also [14] for the calculation of proton decay rate for a virtual N=1 SU(5) model in the context of $Z_2 \times Z_2$ orientifolds and also [18] for complementary considerations on stringy proton decay for SU(5) and flipped SU(5) GUTS]. Hence, it is guaranteed that the scalar mediated proton decay modes are suppressed. The chiral fermions H_u, H_d, receive a Dirac mass from the last term in eqn. (6.3).

• **Model B**

An alternative class of N=0 supersymmetric models, where also all exotics are massive, can be derived from the models appearing in table (11) by the exchanges

$$L \leftrightarrow H_d, \quad d_L^c \leftrightarrow X_2, \tag{6.5}$$

which can be obviously be chosen due to the degeneracy of their hypercharge. The spectrum of the new models can be seen in table (13). The Yukawa couplings for quarks, leptons and exotics colour triplets X_i are

$$\begin{aligned} Y_{(table\ 13)} \ = \ & \lambda_d Q_L d_L^c H_d^H S_5^H/M_s \ + \ \lambda_e L e_L^+ H_d^H S_5^H/M_s \ + \ \lambda_\nu L \nu_L^c H_u^H S_5^H/M_s \ + \\ & X_1 X_2 (\lambda_x^{(1)} S_3^H S_1^H + \lambda_x^{(2)} S_4^H S_5^H) \ . \end{aligned} \tag{6.6}$$

We observe that there is a universality in the dependence of the mass terms for the down quark, the electron and the neutrino mass on the vev of the S_5 previously massive superpartner. The latter Higgs tachyonic field can generate natural mass scales of the electroweak order in the following sence. Take for example the mass for the d-quark. Its mass is given by $m_d = \lambda_d u_d$, where $\langle H_d^H \rangle = \upsilon_d$. Thus the required hierarchy for the mass of the d-quark, $m_d^{exp} = 0.05$ GeV, may be generated from the exponential suppression generated by the Yukawa coupling factor λ_d of the relevant four point function. The fermions H_u, H_d receive a non-zero mass from the Yukawa interaction terms

$$H_u H_d (\lambda_\mu^{(1)} S_3^H S_1^H/M_s + \lambda_\mu^{(2)} S_4^H S_5^H/M_s) \tag{6.7}$$

Matter for $\mathbf{Y^1}$	Y^1	$(SU(3) \times SU(2))_{(Q_a,\ Q_b,\ Q_c,\ Q_d,\ Q_e)}$
$\{Q_L\}$	1/6	$3(3, \bar{2})_{(-1,\ 1,\ 0,\ 0,\ 0)}$
$\{u_L^c\}$	−2/3	$3(\bar{3}, 1)_{(-2,\ 0,\ 0,\ 0,\ 0)}$
$\{e_L^+\}$	1	$3(1, 1)_{(0,\ 2,\ 0,\ 0,\ 0)}$
$\{d_L^c\}$	1/3	$3(1, 1)_{(1,\ 0,\ 0,\ 0,\ 1)}$
$\{H_u\}$	1/2	$3(1, 2)_{(0,\ 1,\ -1,\ 0,\ 0)}$
$\{H_d\}$	−1/2	$3(1, 2)_{(0,\ -1,\ 0,\ 1,\ 0)}$
$\{L\}$	−1/2	$3(1, 2)_{(0,\ -1,\ 0,\ 0,\ 1)}$
$\{S_3 \equiv \nu_L^c\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 1,\ 0)}$
$\{S_1\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ -2,\ 0)}$
$\{S_2\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ 0,\ -2)}$
$\{S_4\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 0,\ 1)}$
$\{S_5\}$	0	$6(1, 1)_{(0,\ 0,\ 0,\ -1,\ -1)}$
$\{X_1\}$	−1/3	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0,\ 0)}$
$\{X_2\}$	1/3	$3(3, 1)_{(1,\ 0,\ 0,\ 1,\ 0)}$

Table 13: The three generation N=0 SM from from five stacks of intersecting branes with its chiral spectrum and three pairs of Higgsinos. On the top of the table the chiral structure of N=1 SM. The middle part exhibits the gauge singlets while the bottom part includes the triplet exotics. These models can come from the models of table (11) by the exchange (6.5). At low energy only the SM survives.

- **Model C**

Another interesting class of N=0 supersymmetric models, where also all exotics are massive, can be derived from the models of table (11) by the exchanges

$$L \leftrightarrow H_d \tag{6.8}$$

These models are further analyzed in appendix C.

- **Model D**

A further N=0 3G 4D model, with the chiral spectrum of the intersecting brane N=1 SM at the string scale, is obtained by the exchange

$$d_L^C \leftrightarrow X_2 \tag{6.9}$$

on the particle spectrum of table (11). These models are examined in appendix D.

- Brane recombination

The string theory recombination process (BR) should be better described by string field theory. For some examples with BR involving classical methods at the level of gauge theory, see [21]. In the present models, BR works as follows : a) Under the BR $\tilde{c} = c+d+e$, the 5-stack models of table (13), flow to the three stack models of table (14).

Matter	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_{\tilde{c}})}$	$U(1)^Y$
$\{Q_L\}$	$3(\bar{3}, 2)_{(-1,\ 1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3, 1)_{(1,\ 0,\ 1)}$	$1/3$
$\{L\}$	$3(1, 2)_{(0,\ -1,\ 1)}$	$-1/2$
$\{e_L^+\}$	$3(1, 1)_{(0,\ 2,\ 0)}$	1
$\{N_R\}$	$3(1, 1)_{(0,\ 0,\ -2)}$	0
$\{S_0\}$	$3(1, 1)_{(0,\ 0,\ -2)}$	0

Table 14: A three generation non-supersymmetric chiral (open string) spectrum accommodating the SM that comes from brane recombination on the 5-stack SM with massive exotics of table (9).

b) Under the BR $\tilde{d} = d+e$, the 5-stack models of table (13), flow to the 4-stack models of table (15).

7 Three generation N=0 SM-like models

7.1 An example of a N=0 Standard-like model

Let us consider the eight stack N=0 model that satisfies the RR tadpole conditions with its effective wrappings given by

$$\begin{aligned}
(Z, Y)_a &= (-1, -1), (Z, Y)_b = (-1, -1), (Z, Y)_{a_1} = (-1, -1), (Z, Y)_{c_1} = (2, 1), \\
(Z, Y)_{c_2} &= (2, 1), \quad (Z, Y)_{c_3} = (2, 1), \quad (Z, Y)_{c_4} = (2, 1), \quad (Z, Y)_{c_5} = (2, 1) \ .
\end{aligned} \tag{7.1}$$

The initial gauge group is based on the structure $U(3)_a \times U(2)_b \times U(1)_{a_1} \times U(1)_{c_1} \times U(1)_{c_2} \times U(1)_{c_3} \times U(1)_{c_4} \times U(1)_{c_5}$. The full chiral spectrum of these N=0 models can be

Matter	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_c, Q_{\bar{d}})}$	$U(1)^Y$
$\{Q_L\}$	$3(\bar{3}, 2)_{(-1,\ 1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0)}$	$-2/3$
$\{X_1 + d_L^c\}$	$6(3, 1)_{(-1,\ 0,\ 0,\ -1)}$	$1/3$
$\{X_2\}$	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0)}$	$-1/3$
$\{H_d + L\}$	$6(1, 2)_{(0,\ -1,\ 0,\ 1)}$	$-1/2$
$\{H_u\}$	$3(1, 2)_{(0,\ 1,\ -1,\ 0)}$	$1/2$
$\{e_L^+\}$	$3(1, 1)_{(0,\ 2,\ 0)}$	1
$\{S_1\}$	$6(1, 1)_{(0,\ 0,\ 1,\ 1)}$	0
$\{S_2\}$	$6(1, 1)_{(0,\ 0,\ 0, -2)}$	0

Table 15: A three generation non-supersymmetric chiral (open string) spectrum accommodating the SM that comes from brane recombination on the 5-stack SM with massive exotics of table (9).

seen in table (17). As we have seen in (7.1) the N=0 models are constructed by combining mainly two different (Z, Y) pairs. Regarding the wrappings (n, m) associated to (Z, Y), we find a number of solutions which can preserve N=1 supersymmetry on a single $U(1)_{c_i}$ D6-brane. They are listed in table (16). We classify the effective wrappings (Z, Y) by the set (l_j, s_i) for convenience. We note that even though the sets of (l_j, s_i) appear to be different, they all give rise to N=0 models with the same spectrum; the latter can be seen in table (17). An example of a choice of (n, m) wrappings is the one associated to the set (l_4, s_3) can be seen in figure 2. The exchange symmetries (4.6) are also valid in these models.

- U(1) anomalies

The analysis of U(1) anomalies shows that there is one U(1) which becomes massive though its couplings to RR fields, namely

$$U(1)^{mas} = 3F_a + 2F_b + F_{a_1} \ , \tag{7.2}$$

Solution	$(Z,\ Y)$	$(n^1,\ m^1)(n^2,\ m^2)(n^3,\ \tilde{m}^3)$	N=1 SUSY Preserved
l_1	$(-1,\ -1)$	$(1,\ 1)(1,\ 0)(1,\ 1)$	$-$
l_2	$(-1,\ -1)$	$(1,\ 0)(1,\ 1)(1,\ 1)$	$-$
l_3	$(-1,\ -1)$	$(1,\ 1)(1,\ 1)(1,\ 0)$	$-$
l_4	$(-1,\ -1)$	$(1,\ 1)(-1,\ 0)(-1,\ -1)$	$-$
l_5	$(-1,\ -1)$	$(-1,\ 0)(1,\ 1)(-1,\ -1)$	$-$
l_6	$(-1,\ -1)$	$(-1,\ -1)(-1,\ 0)(1,\ 1)$	$-$
l_7	$(-1,\ -1)$	$(-1,\ -1)(-1,\ -1)(1,\ 0)$	$-$
l_8	$(-1,\ -1)$	$(-1,\ -1)(1,\ 0)(-1,\ -1)$	$-$
l_9	$(-1,\ -1)$	$(1,\ 0)(-1,\ 0)(1,\ 1)$	$-$
s_1	$(2,\ 1)$	$(1,\ 1)(0,\ 1)(-1,\ 0)$	r_3
s_2	$(2,\ 1)$	$(0,\ 1)(-1,\ 0)(1,\ 1)$	r_3
s_3	$(2,\ 1)$	$(-1,\ 0)(1,\ 1)(0,\ 1)$	r_3
s_4	$(2,\ 1)$	$(1,\ 1)(0,\ -1)(1,\ 0)$	r_3
s_5	$(2,\ 1)$	$(0,\ -1)(1,\ 1)(1,\ 0)$	r_3
s_6	$(2,\ 1)$	$(1,\ 0)(0,\ -1)(1,\ 1)$	r_3
s_7	$(2,\ 1)$	$(0,\ 1)(-1,\ -1)(1,\ 0)$	r_3
s_8	$(2,\ 1)$	$(-1,\ -1)(0,\ 1)(1,\ 0)$	r_3
s_9	$(2,\ 1)$	$(1,\ 0)(0,\ -1)(1,\ 1)$	r_3

Table 16: Wrapping numbers of the eight stack 4D N=0 three generation intersecting D6-brane models. The branes associated with the choices s_i preserve N=1 SUSY.

while the hypercharge which remains massless is given by $(1/3)F_a - (1/2)F_b$. There is also a third $U(1)^c = (3/2)F_a + F_b - (13/2)F_{a_1}$ which can be broken by the vev of the tachyon singlet superpartner of S_0, and also five more U(1)'s which are linear combinations of all five U(1)'s, $U(1)^{c1}, \cdots, U(1)^{c5}$ and can be broken e.g. by the vev's of one of the singlet tachyonic superpartners of $S_1, \cdots, S_5$. As there are more tachyonic singlets available in the models e.g. $S_1, \cdots, S_9$, there are different choices of singlets that could be used to break the extra, beyond the hypercharge, surviving massless the Green-Schwarz mechanism U(1)'s.

- Chiral Spectrum

Most of the matter becomes massive by appropriate Yukawa couplings - denoted in table (17) by using the "+″ sign - while there are only [10] two pairs of chiral fields - where

[10] apart from the *up*-quarks which are massless

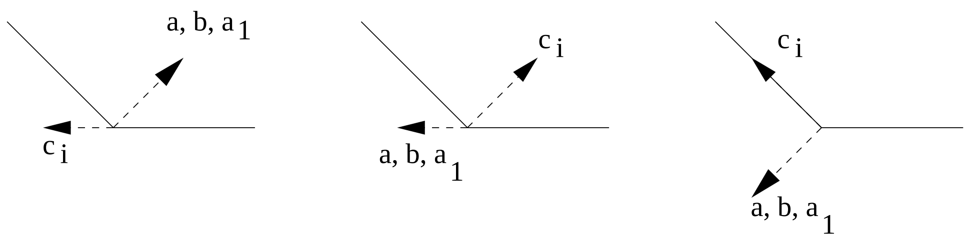

Figure 2: Brane positions in the Standard-like Models of table (3) for the wrapping choices of the set solution (l_4, s_3).

the matter in each pair has opposite hypercharges with respect to the the surviving gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$ - that we were not able to find a mass term; denoted in table (17) by using the "$-$" sign. However, if this model is semirealistic it is worthwhile to examine some of its revealing phenomenology.

The Yukawa couplings of the models are given [11] by

$$Y \;= Y_{(SM)} + Y_{\mu} + Y_{X_0} + Y_{X_i}, \tag{7.3}$$

where

$$Y_{(SM)} = \; \lambda_d Q_L d_L^c \tilde{H}_d^2 + \lambda_e L e_L^+ \tilde{H}_d^2 + \lambda_\nu L N_R \tilde{H}_u, \tag{7.4}$$

$$\begin{aligned} Y_\mu = \lambda_{H_d^1} H_u H_d^1 \tilde{S}_2 + \lambda_{H_d^2} H_u H_d^2 \tilde{S}_1 + \lambda_{H_d^3} H_u H_d^3 \tilde{S}_4 + \lambda_{H_d^4} H_u H_d^4 \tilde{S}_3 + \lambda_{H_d^5} H_u H_d^5 \tilde{S}_6 + \\ \lambda_{H_d^6} H_u H_d^6 \tilde{S}_5 + \lambda_{H_d^7} H_u H_d^7 \tilde{S}_8 + \lambda_{H_d^8} H_u H_d^8 \tilde{S}_7 + \lambda_{H_d^9} H_u H_d^9 \tilde{S}_{10} + \lambda_{H_d^{10}} H_u H_d^{10} \tilde{S}_9 \end{aligned} \tag{7.5}$$

$$\begin{aligned} Y_{X_0} \;=\; \lambda_{X_1^m} X_0 X_1 \tilde{S}_1 \;+ \lambda_{X_2^m} X_0 X_2 \tilde{S}_4 \;+ \lambda_{X_3^m} X_0 X_3 \tilde{S}_3 \;+ \lambda_{X_4^m} X_0 X_4 \tilde{S}_6 \;+ \\ \lambda_{X_5^m} X_0 X_5 \tilde{S}_5 \;+ \lambda_{X_6^m} X_0 X_6 \tilde{S}_8 \;+\; \lambda_{X_7^m} X_0 X_7 \tilde{S}_7 \;+\; \lambda_{X_8^m} X_0 X_8 \tilde{S}_{10} \;+\; \lambda_{X_9^m} X_0 X_9 \tilde{S}_9 \end{aligned} \tag{7.6}$$

$$\begin{aligned} Y_{X_i} \;=\; \lambda_{X_1} Q_L X_1 \tilde{H}_d^1 + \lambda_{X_2} Q_L X_2 \tilde{H}_d^4 + \lambda_{X_3} Q_L X_3 \tilde{H}_d^3 + \lambda_{X_4} Q_L X_4 \tilde{H}_d^6 \;+ \\ \lambda_{X_5} Q_L X_5 \tilde{H}_d^5 \;+\; \lambda_{X_6} Q_L X_6 \tilde{H}_d^8 \;+\; \lambda_{X_7} Q_L X_7 \tilde{H}_d^7 \;+ \\ \lambda_{X_8} Q_L X_8 \tilde{H}_d^{10} \;+\; \lambda_{X_9} Q_L X_9 \tilde{H}_d^9 \end{aligned} \tag{7.7}$$

- Quark, lepton and extra matter masses:

[11] By $\tilde{H}_u$, $\tilde{H}_d^i$, $\tilde{S}_i$ we denote the boson tachyon superpartners of the chiral matter fields H_u, H_d^i, S_i.

Matter	*Massive*	$(SU(3) \times SU(2))_{(Q_a,Q_b,Q_{a1},Q_{c1},Q_{c2},Q_{c3},Q_{c4},Q_{c5})}$	$U(1)^Y$
$\{Q_L\}$	$+$	$3(3^*,2^*)_{(-1,\ -1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$1/6$
$\{u_L^c\}$	$-$	$3(3,1)_{(2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0,\ 0)}$	$1/3$
$\{H_u\}$	$+$	$3(1,2^*)_{(0,\ -1,\ -1,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$1/2$
$\{H_d^2\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 1,\ 0,\ 0,\ 0,\ 0)}$	$-1/2$
$\{e_L^+\}$	$+$	$3(1,1)_{(0,\ -2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	1
$\{X_1\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 1,\ 0,\ 0,\ 0,\ 0,)}$	$1/3$
$\{X_2\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0)}$	$1/3$
$\{X_3\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 1,\ 0,\ 0,\ 0)}$	$1/3$
$\{X_4\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ -1,\ 0,\ 0)}$	$1/3$
$\{X_5\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ 1,\ 0,\ 0)}$	$1/3$
$\{X_6\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ 0,\ -1,\ 0)}$	$1/3$
$\{X_7\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 1,\ 0)}$	$1/3$
$\{X_8\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ -1)}$	$1/3$
$\{X_8\}$	$+$	$3(3,1)_{(1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 1)}$	$1/3$
$\{H_d^1 \equiv L\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ -1,\ 0,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^3\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^4\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 1,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^5\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ -1,\ 0,\ 0)}$	$-1/2$
$\{H_d^6\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 1,\ 0,\ 0)}$	$-1/2$
$\{H_d^7\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ -1,\ 0)}$	$-1/2$
$\{H_d^8\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 1,\ 0)}$	$-1/2$
$\{H_d^9\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 0,\ -1)}$	$-1/2$
$\{H_d^{10}\}$	$+$	$3(1,2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 1)}$	$-1/2$
$\{S_0\}$	$+$	$3(1,1)_{(0,\ 0,\ -2,\ 0,\ 0,\ 0,\ 0,\ 0)}$	0
$\{S_1\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ -1,\ 0,\ 0,\ 0,\ 0)}$	0
$\{S_2 \equiv N_R\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 1,\ 0,\ 0,\ 0,\ 0)}$	0
$\{S_3\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ -1,\ 0,\ 0,\ 0)}$	0
$\{S_4\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 1,\ 0,\ 0,\ 0)}$	0
$\{S_5\}$	$+$	$3(1,1)_{(1,\ 0,\ 1,\ 0,\ 0,\ -1,\ 0,\ 0)}$	0
$\{S_6\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 0,\ 1,\ 0,\ 0)}$	0
$\{S_7\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 0,\ 0,\ -1,\ 0)}$	0
$\{S_8\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 0,\ 0,\ 1,\ 0)}$	0
$\{S_9\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 0,\ 0,\ 0,\ -1)}$	0
$\{S_{10}\}$	$+$	$3(1,1)_{(0,\ 0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 1)}$	$1/3$
$\{X_0\}$	$+$	$3(3,1)_{(-1,\ 0,\ -1,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$-1/3$
$\{Q_1\}$	$-$	$3(3,1)_{(2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$2/3$
$\{Q_2\}$	$-$	$3(6^*,1)_{(-2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$-2/3$
$\{P_1\}$	$-$	$3(1,1)_{(0,\ 2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	-1
$\{P_2\}$	$-$	$3(1,3^*)_{(0,\ -2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$+1$

Table 17: The fermion spectrum of the three generation N=1 SM on top of the table, in addition to three N_R's and three pairs of H_u, H_d chiral matter. These models are non-supersymmetric.

The first Yukawa term $Y_{(N=1\ SM)}$ in (7.3) generates mass terms for all SM matter but the up-quarks, where we have identify the right neutrinos with the singlets S_2. Even though the present models lack a mass term for the up-quarks, it is intersesting to engage in a short description of the phenomenology of these models.

The $\tilde{H}_u$, $\tilde{H}_d^2$ Higgses - play the role of the corresponding two Higgs doublets in the MSSM - couple to the SM matter at tree level. A comment is in order.

• *The Higgses $\tilde{H}_u$, $\tilde{H}_d^2$ can both be made tachyonic* by varying the distance between the branes. For example let us make the choice of wrappings (l_2, s_5). The masses of the scalars $\tilde{H}_u$, $\tilde{H}_d^2$ Higgses are associated with the choices

$$\begin{aligned} \tilde{H}_u \rightarrow \alpha' m^2_{\tilde{H}_u} \equiv \alpha' m^2_{bc^\star} &= \frac{1}{2}(+\,\theta_1 - \theta_2 + \theta_3) = \frac{3Z_1}{4\pi^2} - \frac{2Z_2}{4\pi^2} + \frac{2\pi}{3}, \\ \tilde{H}_d^2 \rightarrow \alpha' m^2_{\tilde{H}_d^2} \equiv \alpha' m^2_{cd^\star} &= \frac{1}{2}(+\,\theta_1 + \theta_2 - \theta_3) = \frac{2Z_2}{4\pi^2} - 4\pi - \frac{3\pi}{2} \end{aligned} \tag{7.8}$$

We can probe the parameter values of the distances in transverse space for which the masses of the Higgses $\tilde{H}_d^2$, $\tilde{H}_d^2$, can both be made tachyonic. By demanding the masses of the $\tilde{H}_d^2$, $\tilde{H}_u$ to be simultaneously tachyonic we get that the following constraint should be satisfied

$$Z_2 \leq 44\pi^3, \quad Z_1 \leq 6\pi^3 \ . \tag{7.9}$$

Another extended see-saw mass matrix is generated by the mixing - in (7.7) and (7.4) - between the d-quarks with the triplets X_i. In the lowest order [12] the see-saw generates contributions to the scalar potential from the 1st term in (7.4) and the 1st term in (7.7) giving us mass eigenvalues of order $\lambda_d \langle \tilde{H}_d^2 \rangle$ and $(\lambda^2_{X_1}/\lambda_d)(\langle \tilde{H}_d^1 \rangle^2 / \langle \tilde{H}_d^2 \rangle)$ for the d-quark, X_1 respectively. A rough estimate on the size of the mass scales involved could be found by e.g. assuming that $\lambda^2_{X_1} \approx 1$. Since $\lambda_d \langle \tilde{H}_d^2 \rangle = 0.005$ GeV we get that the mass of the triplet X_1 should be of the order of 10^6 GeV which is very low to be phenomenogically acceptable.

The term Y_{X_0} generates Dirac mass term couplings of the triplet X_0 to the rest of the triplets X_i after the tachyon singlets $\tilde{S}_i$, $i = 1, \cdots, 9$ obtain a vev. The present mechanism of generating a Dirac mass of the triplets, is identical to the one appearing in models of the fermionic formulation [40].

As we already have seen in (7.7) there are already contributions to the mass terms that are being generated by trilinear Yukawa type couplings in Y for X_i, i=1,..,9. Thus whether

[12] and assuming that we neglect the couplings λ_{X_i}, $i \neq 1$; e.g. $\lambda_{X_i} \rightarrow 0$

or not (7.7) is also present when the - terms (7.6) are, will be decided when the relevant string amplitudes will be calculated. If for example it is found that $\lambda_{X_i^m} \equiv 0,\ i \neq 1$; $\lambda_{X_i} \neq 0, i \neq 1$ then all extra triplets X_0, X_i, $i = 1, \cdots, 9$ obtain a mass; the pair (X_1, X_0) by forming a Dirac term while the rest of the X_i triplets by generating a see-saw mixing with the first term in (7.4).

The neutrinos get also a tree level mass from a Yukawa term in (7.4) as we had identify $N_R \equiv S_2$. If for example we had identify N_R with e.g. S_0, the only mass term allowed for the neutrinos would have been the $LN_R\langle Q_L d_L^c\rangle \tilde{S}_2^2/M_s^3$, which depends on the vev of the chiral condensate $d_R d_L$ and is excluded as it is very suppressed. The Y_μ-term in (7.5) - which in a supersymmetric theory could play the role of the μ-term - represents mass term mixing between the chiral matter H_u and the H_d^i, $I = 1, \cdots, 9$.

Apart from the u-quark for which there is no obvious mass term, we also find that there are no mass terms for the Q_1, Q_2, P_1, P_2, multiplets. The latter fields are obviously non-chiral with respect to the surviving gauge group $SU(3) \times SU(2) \times U(1)_Y$.

7.2 A second example of a Standard-like model

An alternative example of a Standard-like model is obtained by changing the identification of fields that appear in table (17). For this purpose we identify the lepton field as $L \equiv H_d^3$. In table (18), we list the chiral structure of the N=0 models. We have not included the S_i, X_i, Q_i, P_i fields as they are the same as the ones appearing in table (17).

Yukawa couplings for the quarks, leptons and the X_i's are given by

$$\tilde{Y} \ = \tilde{Y}_{(N=1\ SM)} + \tilde{Y}_\mu + \tilde{Y}_{X_0} + \tilde{Y}_{X_i}, \tag{7.10}$$

where

$$\tilde{Y}_{(N=1\ SM)} = \ \lambda_d Q_L d_L^c \tilde{H}_d^2 + \lambda_e L e_L^+ \tilde{H}_d^4 + \lambda_\nu L N_R \tilde{H}_u \tilde{S}_0 \tilde{S}_1 \tilde{S}_4/M_s^3, \tag{7.11}$$

$$\tilde{Y}_\mu = Y_\mu,\ \tilde{Y}_{X_0} = Y_{X_0},\ \tilde{Y}_{X_i} = Y_{X_i}, \tag{7.12}$$

As in the models of the previous section, the non-chiral fields Q_i, P_i, u_L^c remain massless. Other N=0 SM-like models can be obtained from the one's in tables (17), (18) by changing the assignment of the right handed neutrinos to any of the singlets S_i and/or the identification of leptons with any of the fields H_d^i.

Matter	*Massive*	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_{a1}, Q_{c1}, Q_{c2}, Q_{c3}, Q_{c4}, Q_{c5})}$	$U(1)^Y$
$\{Q_L\}$	$+$	$3(3^*, 2^*)_{(-1,\ -1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$1/6$
$\{u_L^c\}$	$-$	$3(3, 1)_{(2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$+$	$3(3, 1)_{(1,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0,\ 0)}$	$1/3$
$\{H_u\}$	$+$	$3(1, 2^*)_{(0,\ -1,\ -1,\ 0,\ 0,\ 0,\ 0,\ 0)}$	$1/2$
$\{H_d^2\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 1,\ 0,\ 0,\ 0,\ 0)}$	$-1/2$
$\{e_L^+\}$	$+$	$3(1, 1)_{(0,\ -2,\ 0,\ 0,\ 0,\ 0,\ 0,\ 0)}$	1
$\{H_d^3 \equiv L\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ -1,\ 0,\ 0,\ 0)}$	$-1/2$
$\{S_2 \equiv N_R\}$	$+$	$3(1, 1)_{(0,\ 0,\ 1,\ 1,\ 0,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^1\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ -1,\ 0,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^4\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 1,\ 0,\ 0,\ 0)}$	$-1/2$
$\{H_d^5\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ -1,\ 0,\ 0)}$	$-1/2$
$\{H_d^6\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 1,\ 0,\ 0)}$	$-1/2$
$\{H_d^7\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ -1,\ 0)}$	$-1/2$
$\{H_d^8\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 1,\ 0)}$	$-1/2$
$\{H_d^9\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 0,\ -1)}$	$-1/2$
$\{H_d^{10}\}$	$+$	$3(1, 2)_{(0,\ 1,\ 0,\ 0,\ 0,\ 0,\ 0,\ 1)}$	$-1/2$

Table 18: A non-supersymmetric SM-like model with the three generation N=1 SM fermion spectrum on top of the table, where only the 2 pairs of exotics Q_i, P_i remain massless (and u_L^c). Also present the X_i, S_i, Q_i, P_i fermions seen in table (17).

8 SPLIT SUPERSYMMETRY & D6-BRANE MODELS with $sin^2(\theta) = \frac{3}{8}$

String Theory Intersecting D-brane models (STIB) is the natural arena for the realization of ideas on the existence of split supersymmetry (SS) [41, 42, 43] in particle physics. The SS claim [41] relies on a number of assumptions that demand :
(a) that the particle spectrum of the SM remain massless to low energies
(b) that the SM spartners become massive with a mass of the order of the supersymmetry breaking scale
(c) the gauge couplings unify at a scale of 10^{16} GeV
(d) there are light gauginos in the presence of gravity [Note that condition should be modified in STIBs as gauginos get a mass of order M_s.]
(e) there are light higgsinos in the presence of gravity and thus can be seen experimentally
(f) the assumption of the existence of a heavy and a light Higgs set of doublets present in the spectrum that form two chiral supermultiplets.
Models will completely satisfy the SS scenario may be presented in [20]. In this section we will present models that can some times fully satisfy conditions (a), (b), (c) (d), (e).

We also note that condition (f), the existence of a Higgs light was assumed in [41] that

it may be a result of a fine tuning mechanism. In models that may come from intersecting branes supersymmetric Higgs sets may appear naturally [20].

The present D-brane models have not a supersymmetric Higgs sector. However, the Higgs system can be understood as part for the massive spectrum that organizes itself in terms of massive N=2 hypermultiplets. The Higgs fields become subsequently tachyonic in order to participate in electroweak symmetry breaking [see also similar considerations [8, 9, 10, 11]].

Conditions (a), (b), (c), (d) can be naturally obtained - in intersecting brane worlds - and in the current models. The (e), (f) conditions are harder to be obtained and may be examined in a case by case basis. Also condition (c) for a particle physics model that includes gravity - as STIBs - means that the string scale should be high and at least 10^{16} GeV.

Condition (a) can be naturally satisfied in STIBS and there are a lot of models exhibiting only the SM spectrum at low energies. These models accommodate the SM spectrum and can be either belong to an overall non-supersymmetric model or to an overall N=1 supersymmetric model. The first case involves three generation models with supersymmetry broken at the string scale as it has been exhibited in the toroidal orientifolds in [8, 9, 10, 11] and where the superpartners of the SM are being massive and of the order of the string scale. It is also possible to construct non-supersymmetric constructions that localize locally the N=1 supersymmetric SM spectrum and such models have been constructed in [16], [17], [36]. In particular in [17] we generalized the four stack constructions of [16] by also including a non-zero B-field flux in the models[also extending these models to their maximal extensions with gauge groups made of five and six stacks of D6-branes at the string scale]. This makes the torus tilded and allows for more general solutions in the RR tadpoles as well changing the number of N=1 Higgs supermultiplets present in the spectrum. In the four stack models constructed in [16, 17] it has been shown [44] that it is possible to accommodate the successful prediction of supersymmetric SU(5) GUTS with $sin^2(\theta) = 3/8$ at a string scale which coincides with the unification scale of $2 \cdot 10^{16}$ GeV, and all gauge coupling constants unified at 10^{16} GeV. Hence condition (c) is also satisfied in IBs and obviously all the D-brane models appearing in [16], [17], [36] could form realistic D-brane split susy models if RR tadpoles is shown to be consistently implemented (such an analysis do not exist at the moment). These issues will be examined in [20]. Next, we will also show that it is also possible - in the framework of the present

$Z_3 \times Z_3$ orientifolds - to easily build models which satisfy conditions (a),(b),(c), (d); some models may also satisfy partially or fully the condition (e).

8.1 Partial Split Susy models: light Gauginos & Higgsinos & $sin^2\theta = \frac{3}{8}$

In this section we will construct a deformation of the SM's appeared in section (3) and table (1) where (a), (b), (c), (d), (e) conditions of split susy are satisfied. These models have the initial gauge group $U(3) \times U(2) \times U(1)$ and at low energy the gauge group become identical to the SM. The massless fermion spectrum is given in table (19). RR tadpoles are satisfied by the choices $N_a = 3$, $N_b = 2$, $N_c = 1$ and

$$(Z_a, Y_a) = \begin{pmatrix} 1, & 1 \end{pmatrix}, \ (Z_b, Y_b) = \begin{pmatrix} 1, & 1 \end{pmatrix}, \ (Z_c, Y_c) = \begin{pmatrix} -1, & 1 \end{pmatrix} \tag{8.1}$$

At the top of the table (19) we see the massless fermion spectrum of the N=1 SM. The corresponding superpartners are part of the massive spectrum and appear in the intersection of each corresponding fermion; hence condition (b) is satisfied. Also, there is a pair of non-chiral colour triplets.

In order to show that at low energy only the SM remains, we have to show that all U(1) gauge fields originally present at the string scale become massive but the hypercharge. Also we have to show that Higginos and the exotics C_i receive non-zero masses.

The Higgsinos [condition (e)] H_u, H_d, form a Dirac mass term from the Yukawa coupling

$$\lambda_H H_u H_d \langle \tilde{N}_R \rangle, \tag{8.2}$$

where $\tilde{N}_R$ is the scalar tachyonic superpartner of N_R. The vev of $\tilde{N}_R$ is of the order of the string scale. Due to nature of the Yukawa coupling term [see eqn. (3.4)] $\lambda_H \sim e^{-A_{hig}}$ the Higgsino mass can be anywhere between the string scale and the scale of electroweak symmetry breaking,

$$100 \ GeV < m_{(Higgino \ pair)} \leq M_s \tag{8.3}$$

which requires the areas to be $A_{min} \sim 34$, $A_{max} = 0$ for the lower and upper limits of (8.3) and a string scale

$$M_s \ = 2 \cdot 10^{16} \ GeV \tag{8.4}$$

Lets us discuss the U(1) structure. One U(1) gauge field becomes massive through its BF couplings, namely $-3F_a - 2F_b - 3F_c$, while from the extra U(1)'s that survive massless

Matter	Intersection	$(SU(3)\times SU(2))_{(Q_a,Q_b,Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$ab*$	$3(3,2)_{(-1,\ -1,\ 0)}$	$1/6$
$\{u_L^c\}$	A_a	$3(3,1)_{(-2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	ac	$3(3,1)_{(1,\ 0,\ -1)}$	$1/3$
$\{\ L\}$	bc	$3(1,2)_{(0,\ 1,\ -1)}$	$-1/2$
$\{\ H_d\}$	bc	$3(1,2)_{(0,\ 1,\ -1)}$	$-1/2$
$\{H_u\}$	$bc*$	$3(1,\bar{2})_{(0,\ -1,\ -1)}$	$1/2$
$\{e_L^+\}$	A_b	$3(1,1)_{(0,\ -2,\ 0)}$	1
$\{N_R\}$	S_c	$9(1,1)_{(0,\ 0,\ 2)}$	0
$\{C_1\}$	ac	$3(3,1)_{(1,\ 0,\ -1)}$	$1/3$
$\{C_2\}$	$ac*$	$3(\bar{3},1)_{(-1,\ 0,\ -1)}$	$-1/3$

Table 19: A three generation 4D non-supersymmetric model with the chiral content of N=1 MSSM on top of the table, in addition to N_R's. There are three pairs of H_u, H_d Higgsinos. Note that this model mimics models coming from gauge mediation scenarios and possess $sin^2(\theta) = 3/8$ at M_s.

the GS mechanism; one combination of U(1)'s is the hypercharge while the third $U(1)^{add}$ gets broken by the vev of $\tilde{N}_R$.

$$U(1)^Y = \frac{1}{3}F_a - \frac{1}{2}F_b, \quad U(1)^{add} = F_a + (2/3)F_b - (13/9)F_c \ . \tag{8.5}$$

We also note that the exotics C_i gets massive by forming a Dirac mass term that couples to $\tilde{N}_R$, namely $C_1C_2\langle\tilde{N}_R\rangle$. As the present $Z_3 \times Z_3$ orientifolds involve D6-branes the gauge coupling constants are controlled by the length of the corresponding cycles that the D6-branes wrap

$$\frac{1}{\alpha_a} \ = \ ||l_i|| \ , \tag{8.6}$$

where $||l_i||$ is the length of the corresponding cycle for the i-th set of brane stacks. The canonically normalized U(1)'s as well the normalization of the abelian generators are given

by

$$\tilde{U}(1)_a = \frac{F_a}{\sqrt{2N_a}}, \quad Tr(T_a T_b) = \frac{1}{2}\delta_{ab} \tag{8.7}$$

The hypercharge is given [13] as a linear combination $Y(1)^Y = \sum_i c_i F_i$; hence in the present models the value of the weak angle is computed to be

$$\sin^2\theta_W = \frac{1}{1 + 4c_2^2 + 6c_3^2(\alpha_2/\alpha_3)} \tag{8.8}$$

Taking into account that in the present models $\alpha_2 = \alpha_3$ we get

$$\sin^2\theta_W \stackrel{M_s}{=} \frac{3}{8} \tag{8.9}$$

Hence two of the gauge couplings unify at the GUT scale of $2 \cdot 10^{16}$ GeV. Thus instead of the unification of all three gauge couplings of the MSSM we succed to get the unification of two of the gauge couplings without the need for N=1 supersymmetry present in the spectrum at the same scale.

Gauginos are massless at tree level in the present intersecting brane models and appear in the four dimensional N=4 SYM spectrum that get localized from strings having both ends on the same set of D6-branes. A mechanism for generating gaugino masses in intersecting branes - due to quantum corrections - have been put forward in [8] where non-supersymmetric toroidal orientifold models are discussed [8, 9, 10, 11]. According to this result [8], as gauginos are massless at tree level, loop corrections to gauginos proceed via massive fermions running in the loops. The order of gaugino masses is of the order of the supersymmetry breaking scale, the string scale. The same mechanism may persist in the present models. A comment is in order. The spectrum of table (19) is invariant under the exchanges $C_1 \leftrightarrow d_L^c$, $L \leftrightarrow H_d$. We also note that the Higgs fields have the quantum numbers

$$\tilde{H}_u = (1, 2, 1)_{(0,-1,-1)}, \quad \tilde{H}_d = (1, 2, 1)_{(0,1,1)} \ . \tag{8.10}$$

8.2 Partial Split Susy models: light Gauginos, no light Higgsinos, $sin^2(\theta) = 3/8$

In this section, we will present models that satisfy (a),(b), (c), (d) conditions of split susy. These models are build from three stacks of intersecting D6-branes at the string scale a

[13] we used the conventions used in [39]

variant of the models considered in section (4.1). The satisfaction of the RR tadpoles (2.2) proceeds via the choice

$$N_a \ = \ 3, \quad N_b \ = \ 2, \quad N_c \ = \ 1 \tag{8.11}$$

and with the choice of effective wrappings

$$(Z_a, Y_a) = \Big(\ 1, \quad 0 \ \Big), \ (Z_b, Y_b) = \Big(\ 1, \quad 0 \ \Big), \ (Z_c, Y_c) = \Big(\ -1, \quad 0 \ \Big) \tag{8.12}$$

The SM fermion spectrum with three quark and lepton families is seen in table (20) There is one anomalous U(1) which becomes massive

Matter	$(SU(3) \times SU(2))_{(Q_a, Q_b, Q_c)}$	$U(1)^Y$
$\{Q_L\}$	$3(3,2)_{(1,\ 1,\ 0)}$	$1/6$
$\{u_L^c\}$	$3(\bar{3},1)_{(2,\ 0,\ 0)}$	$-2/3$
$\{d_L^c\}$	$3(3,1)_{(-1,\ 0,\ 1)}$	$1/3$
$\{L\}$	$3(1,2)_{(0,\ -1,\ -1)}$	$-1/2$
$\{e_L^+\}$	$3(1,1)_{(0,\ -2,\ 0)}$	1
$\{N_R\}$	$3(1,1)_{(0,\ 0,\ 2)}$	0

Table 20: A three generation chiral (open string) spectrum accommodating the SM. The required Higgs may come from bifundamental N=2 hypermultiplets in the N=2 bc, $bc^{\star}$ sectors [8, 9, 10] that may trigger brane recombination.

$$U(1)^{massive} = 3F_a + 2F_b - 2F_c \tag{8.13}$$

and from the two anomaly free U(1)'s. One of them which can be identified

$$U(1)_{ex} \ = \ 3F_a + 2F_b - \frac{13}{2} F_c \tag{8.14}$$

becomes massive by the vev of the tachyonic scalar superpartner of the right handed neutrino, leaving only the hypercharge massless to low energies

$$U(1)^Y = -\frac{1}{3} F_a + \frac{1}{2} F_b \tag{8.15}$$

Light Higgsinos are not present in the models considered in this section as they are part of the massive spectrum with a mass of the order of the string scale. Gauginos are expected to receive string scale masses. The strong and weak gauge couplings also unify and $sin^2(M_{GUT}) = 3/8$ in the present models at $M_s = 2 \cdot 10^{16}$ GeV.

9 CONCLUSIONS

In this work, we have examined the construction of three family non-susy models in intersecting brane worlds within the context $Z_3 \times Z_3$ orientifolds [19] with D6-branes intersecting at angles and starting gauge groups - at the string scale - in the form $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)^n$. In all constructions - the u_L^c - is in the antisymmetric representation of SU(3) - and thus the u-quark mass term is not allowed by charge conservation. We started our investigation for the construction of three generation N=0 models by starting with the simplest construction that could accommodate the Standard Model gauge group that is using three stacks. At 3- /5-stacks we found N=0 supersymmetric vacua with the chiral spectrum of the N=1 SM, with 3 species of right handed neutrinos and 3 pairs of chiral fermions H_u, H_d that play the role of the MSSM Higgsinos. These extra fermions receive masses of order of the string scale. We also found 3-stack vacua with only the SM spectrum. These models break to only the SM at low energy.

- Comparison to Models with Fluxes

  As in the present N=0 perturbative string models, all complex structure moduli are fixed - RR tadpoles disappear - the effect of the orbifold symmetries that fix moduli is equivalent to the effects of models with fluxes have [45].

Even though the present N=0 models do not allow a mass term for the u-quarks, we hope in the feature to be able to construct models where these problems are solved. In fact, as it is shown in [19] that GUT models with the flipped SU(5) gauge group have no mass term for the down-quarks that makes them more promising - as the lack of the relevant Yukawa could be bypassed in perturbation theory - since the down-quark masses are small [14].

[14] we thank G. Kane for this remark

- Split Supersymmetry Models

  Models considered in the last sections of our work, show us that in intersecting brane worlds it would be possible to construct realictic split susy models - even though a lot of work is also needed to be performed - that not only can drive us to a successful prediction of the SU(5) GUT value for the Weinberg angle at the unification scale but also incorporate light Higgsinos and string (GUT) scale gauginos, bringing us closer to an exact implementation of split supersymmetry [46] scenario in intersecting D-brane models. We also note that as we noted gauginos are not light in STIBs - as it was expected in non-string based split susy scenarios [41] - since they receive string scale masses.

Summarizing, at present, in the absence of realistic N=1 supersymmetric models with no massless exotics from intersecting brane worlds without [or with] fluxes, non-susy intersecting D6-brane model building results are more powerful, as on these cases the constructions have either only the SM spectrum at low energy with no exotics present [sections 4 and [8, 9, 10, 11]] or in cases possess the required couplings that could give masses to the extra non-chiral colour triplet exotics present in particular constructions [sections 3, 8] and even achieve the $sin^2\theta = 3/8$ values at the GUT scale with a unification of only two of the gauge couplings, the strong and weak gauge couplings [section 8]. Hence in some of the present SM constructions we can satisfy most (partially split susy) of the conditions required for a fully realistic split susy string model.

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Note added

While this revised work and [19], [20] were finished and were being prepared for submission we noticed [46] that also studied split supersymmetry scenarios in relation to models coming from intersecting branes. In fact the SM configuration used in model A of [46] is the one used in sections (4.1) and (8.2) of this work.

10 Appendix A

Wrappings, subject to the interchanges (4.6), generating the SM's of table (3) may be seen in tables (21), (22), (23).

Brane	$(n^1, m^1) \times (n^2, m^2) \times (n^3, m^3)$	SUSY preserved
$\{a\}$	$(0,\ 1) \times (1,\ 0) \times (0,\ -1)$	–
$\{b\}$	$(1,\ 0) \times (1,\ 1) \times (-1, -1)$	–
$\{c\}$	$(1,\ \ 1) \times (1,\ 1) \times (1,\ \ 0)$	–

Table 21: Wrapping numbers in the three stack D6-brane N=0 SMs of table (3). These wrappings come from the change $(n,m)_a \leftrightarrow (n,m)_b$ in the wrappings of table (5).

11 Appendix B

In this appendix, we apply the exchanges (4.6) to the wrappings of table (12). The resulting models have the same spectrum as the N=0 five stack Standard Models of table (11). These choices of wrappings can be seen in tables (24), (25), (26).

Brane	$(n^1,m^1)\times(n^2,m^2)\times(n^3,m^3)$	SUSY preserved
$\{a\}$	$(0,\ -1)\times(0,\ 1)\times(1,\ 0)$	–
$\{b\}$	$(-1,\ -1)\times(1,\ 0)\times(1,1)$	–
$\{c\}$	$(1,\ \ 0)\times(1,\ 1)\times(1,\ \ 1)$	–

Table 22: Wrapping numbers in the three stack N=0 SMs of table (3). These wrappings come from the change $(n,m)_a \leftrightarrow (n,m)_c$ in the wrappings of table (5).

Brane	$(n^1,m^1)\times(n^2,m^2)\times(n^3,m^3)$	SUSY preserved
$\{a\}$	$(1,\ 0)\times(0,\ -1)\times(0,\ 1)$	–
$\{b\}$	$(1,\ 1)\times(-1,\ -1)\times(1,0)$	–
$\{c\}$	$(1,\ \ 1)\times(1,\ 0)\times(1,\ \ 1)$	–

Table 23: Wrapping numbers in the three stack SMs of table (3). These wrappings come from the change $(n,m)_b \leftrightarrow (n,m)_c$ in the wrappings of table (5).

12 Appendix C

• Model C

The spectrum of the new N=0 three generation models appearing in this appendix is derived from the exchange (6.8) on the five stack models of table (11). The spectrum can be seen in table (27). The Yukawa couplings for the quarks, leptons are given by

$$\begin{aligned} Y_{(table\ 27)} \;=\; & \lambda_d Q_L d_L^c H_d^H S_5^H/M_s \;+\; \lambda_e L e_L^+ H_d^H S_5^H/M_s \;+\; \lambda_\nu L \nu_L^c H_u^H S_5^H/M_s \;+ \\ & X_1 X_2 (\lambda_x^{(1)} S_4^H S_2^H + \lambda_x^{(2)} S_3^H S_5^H)/M_s \ , \end{aligned} \tag{12.1}$$

where the superscript H denotes the tachyonic scalar superpartner of the corresponding fermion. These models allow for a universal dependence of the masses of all the quarks and leptons on the tachyonic Higgs vev of the superpartner of S_5. The fermions H_u, H_d get massive by the following Yukawa terms

$$H_u H_d (\lambda_\mu^{(1)} S_3^H S_1^H + \lambda_\mu^{(2)} S_4^H S_5^H)/M_s \tag{12.2}$$

Brane	$(n^1, m^1)(n^2, m^2)(n^3, m^3)$	SUSY Preserved
$\{a\}$	$(1,\ 0)(1,\ 1)(-1,\ -1)$	$-$
$\{b\}$	$(0,\ 1)(1,\ 0)(0, -1)$	$-$
$\{c\}$	$(1,\ 0)(1,\ 1)(-1,\ -1)$	$-$
$\{d\}$	$(1,\ 0)(1,\ 1)(1,\ 1)$	$-$
$\{e\}$	$(1,\ 1)(1,\ 1)(1,\ 0)$	$-$

Table 24: Wrapping numbers responsible for the N=0 five stack 4D three generation intersecting D6-brane SMs of table (11). These models are derived from table (12) by the interchange $(n, m)_a \leftrightarrow (n, m)_b$.

Brane	$(n^1, m^1)(n^2, m^2)(n^3, m^3)$	SUSY Preserved
$\{a\}$	$(-1,\ -1)(1,\ 0)(1,\ 1)$	$-$
$\{b\}$	$(0,\ -1)(0,\ 1)(1, 0)$	$-$
$\{c\}$	$(-1,\ -1)(1,\ 0)(1,\ 1)$	$-$
$\{d\}$	$(1,\ 1)(1,\ 0)(1,\ 1)$	$-$
$\{e\}$	$(1,\ 0)(1,\ 1)(1,\ 1)$	$-$

Table 25: Wrapping numbers responsible the N=0 five stack 4D three generation intersecting D6-brane SMs of table (11). These models are derived from table (12) by the interchange $(n, m)_a \leftrightarrow (n, m)_c$.

13 Appendix D

• Model D

The spectrum of the new N=0 three generation models appearing in this appendix is derived from the exchange (6.9) on the five stack models of table (11). It can be seen in table (28). Yukawa's for the quarks, leptons, and the X_i triplets are given by

$$\begin{aligned} Y_{(table\ 28)} \ &= \ \lambda_d Q_L d_L^c H_d^H S_2^H / M_s \ + \ \lambda_e L e_L^+ H_d^H S_5^H / M_s \ + \ \lambda_\nu L \nu_L^c H_u^H S_1^H / M_s \ + \\ & X_1 X_2 (\lambda_x^{(1)} S_4^H S_5^H + \lambda_x^{(2)} S_3^H S_1^H)/M_s \ + \ H_u H_d (\lambda_\mu^{(1)} S_4^H S_2^H + \lambda_\mu^{(2)} S_3^H S_5^H)/M_s \end{aligned} \quad (13.1)$$

In fact, if $\langle S_5^H \rangle \approx \langle S_2^H \rangle \approx \langle S_1^H \rangle \approx M_s$, then the masses of the quarks and leptons depend

Brane	$(n^1, m^1)(n^2, m^2)(n^3, m^3)$	SUSY Preserved
$\{a\}$	$(1,\ 1)(-1,\ -1)(1,\ 0)$	–
$\{b\}$	$(1,\ 0)(0,\ -1)(0, 1)$	–
$\{c\}$	$(1,\ \ 1)(-1,\ -1)(1,\ \ 0)$	–
$\{d\}$	$(1,\ 1)(1,\ 1)(1,\ 0)$	–
$\{e\}$	$(1,\ 1)(1,\ 0)(1,\ 1)$	–

Table 26: Wrapping numbers responsible for the N=0 five stack 4D three generation intersecting D6-brane SMs of table (11). These models are derived from table (12) by the interchange $(n,m)_b \leftrightarrow (n,m)_c$.

universally on the scale of the electroweak symmetry breaking, assuming $\langle H_u \rangle \approx \langle H_d \rangle$. The "Higgsinos" H_u, H_d, also get a non-zero mass from the last term in (13.1).

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Matter for $\mathbf{Y^1}$	Y^1	$(SU(3) \times SU(2))_{(Q_a,\ Q_b,\ Q_c,\ Q_d,\ Q_e)}$
$\{Q_L\}$	$1/6$	$3(3, \bar{2})_{(-1,\ 1,\ 0,\ 0,\ 0)}$
$\{u_L^c\}$	$-2/3$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0,\ 0,\ 0)}$
$\{e_L^+\}$	1	$3(1, 1)_{(0,\ 2,\ 0,\ 0,\ 0)}$
$\{d_L^c\}$	$1/3$	$3(1, 1)_{(1,\ 0,\ 0,\ 1,\ 0)}$
$\{H_u\}$	$1/2$	$3(1, 2)_{(0,\ 1,\ -1,\ 0,\ 0)}$
$\{H_d\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 1,\ 0)}$
$\{L\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 0,\ 1)}$
$\{S_3 \equiv \nu_L^c\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 1,\ 0)}$
$\{S_1\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ -2,\ 0)}$
$\{S_2\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ 0,\ -2)}$
$\{S_4\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 0,\ 1)}$
$\{S_5\}$	0	$6(1, 1)_{(0,\ 0,\ 0,\ -1,\ -1)}$
$\{X_1\}$	$-1/3$	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0,\ 0)}$
$\{X_2\}$	$1/3$	$3(3, 1)_{(1,\ 0,\ 0,\ 0,\ 1)}$

Table 27: The three generation N=0 SM chiral spectrum from from five stacks of intersecting branes with its chiral spectrum with three pairs of Higgsinos. On the top of the table the chiral structure of N=1 SM with right handed neutrinos. The middle part exhibits the extra gauge singlets while the bottom part includes the triplet exotics. These models can come from the models of table (11) by the exchange (6.8).

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Matter for $\mathbf{Y^1}$	Y^1	$(SU(3) \times SU(2))_{(Q_a,\ Q_b,\ Q_c,\ Q_d,\ Q_e)}$
$\{Q_L\}$	$1/6$	$3(3, \bar{2})_{(-1,\ 1,\ 0,\ 0,\ 0)}$
$\{u_L^c\}$	$-2/3$	$3(\bar{3}, 1)_{(-2,\ 0,\ 0,\ 0,\ 0)}$
$\{e_L^+\}$	1	$3(1, 1)_{(0,\ 2,\ 0,\ 0,\ 0)}$
$\{d_L^c\}$	$1/3$	$3(1, 1)_{(1,\ 0,\ 0,\ 0,\ 1)}$
$\{H_u\}$	$1/2$	$3(1, 2)_{(0,\ 1,\ -1,\ 0,\ 0)}$
$\{H_d\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 0,\ 1)}$
$\{L\}$	$-1/2$	$3(1, 2)_{(0,\ -1,\ 0,\ 1,\ 0)}$
$\{S_3 \equiv \nu_L^c\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 1,\ 0)}$
$\{S_1\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ -2,\ 0)}$
$\{S_2\}$	0	$3(3, 1)_{(0,\ 0,\ 0,\ 0,\ -2)}$
$\{S_4\}$	0	$3(1, 1)_{(0,\ 0,\ 1,\ 0,\ 1)}$
$\{S_5\}$	0	$6(1, 1)_{(0,\ 0,\ 0,\ -1,\ -1)}$
$\{X_1\}$	$-1/3$	$3(\bar{3}, 1)_{(-1,\ 0,\ -1,\ 0,\ 0)}$
$\{X_2\}$	$1/3$	$3(3, 1)_{(1,\ 0,\ 0,\ 1,\ 0)}$

Table 28: The three generation N=1 SM from from five stacks of intersecting branes with its chiral spectrum with three pairs of Higgsinos and right neutrinos. On the top of the table the chiral structure of N=1 SM. The middle part exhibits the gauge singlets while the bottom part includes the triplet exotics. These models can come from the models of table (11) by the exchange (6.9).

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